NREL's Village Power Models

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Why do we need new models?

- Traditional Rural Electrification
  - Grid extensions, micro-hydro or diesels
- New and Renewable Alternatives
  - Small-scale Individual DC systems
    - Solar Lanterns, Solar or Wind Home Systems
  - Hybrid Power AC Systems
    - Wind, PV, Batteries, Gensets
    - Mini-grids, Micro-enterprise Zones, Battery Recharging Stations

Traditional Rural Electrification

- Grid extensions and diesels are excellent for large loads
  - Grid extension is very costly for remote loads
  - Diesels have high hourly operating cost
    - Often only run for limited hours per day
- Micro-hydro is excellent but very site-specific
- With limited alternatives the best choice is usually obvious

New Alternatives

- Grid extension vs mini-grid vs individual systems
- Solar vs wind
- Batteries vs genset
- Hybrids and mixed systems often best
- Large differences in quality of power
  - AC vs DC
  - Part-time power vs 24 hour power

The Role of Models

- Objective and subjective criteria
  - Computer analyze objective criteria
  - People analyze subjective criteria
- It is easier to weigh the quality of service issues when you have comparable cost estimates for each alternative
- Simplicity and Transparency

The Role of Models (Cont.)

- Educational role
- Screening role
- Regulatory role
- Finance, economics and tariff design
- System design role

NREL Models

- **ViPOR:** An optimization model that determines the best mix of centralized and isolated power generation for a particular village.
- **HOMER:** An optimization model that determines the least-cost hybrid system configuration.
- **Hybrid2:** A simulation model to determine the cost and performance of a wide variety of hybrid or conventional power systems given the load and available resource.

Village Power Optimization Model for Renewables

ViPOR is an optimization model for designing village electrification systems. It is able to:

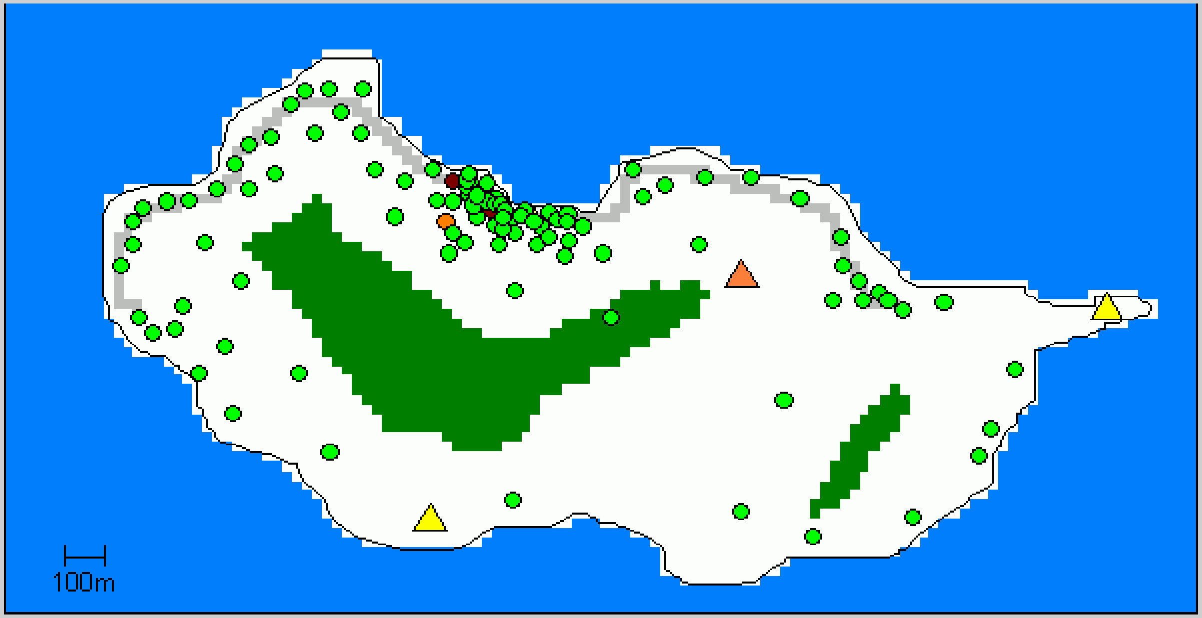
- Optimize the mix of centralized and isolated generation
- Select between grid extension and hybrid system for centralized power
- Select the optimal placement of the centralized power system(s)
- Determine the optimal placement of transformers
- Design the optimal MV and LV distribution grid

The optimization procedure considers both costs and revenues.

ViPOR: Inputs

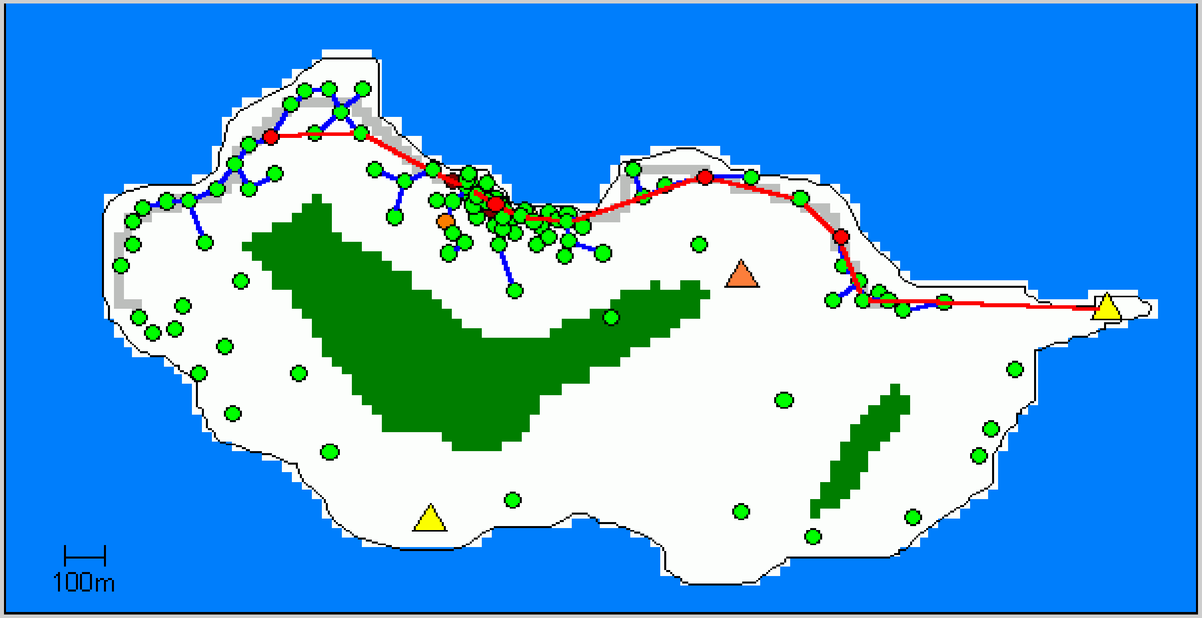
- Location and power requirements of each expected load
- Potential locations of centralized power system
- Wire and transformer costs
- Electrical generation costs for isolated and centralized power systems (calculated by HOMER)
- Expected revenues from each load (on-grid and off-grid)
- Terrain description
- Maximum low voltage line length

ViPOR: Sample village



- Water is shown in blue, forest green, grass white, and trail gray.
- Green dots are houses, brown are stores, orange is church.
- Yellow triangles are high-wind sites, orange is low-wind site.

ViPOR: Solution for sample village



- Red lines are MV wires, blue are LV wires, and red dots are transformers.
- ViPOR has chosen a high-wind site to power the centralized system.
- Houses not on the grid are to be given PV home systems.

ViPOR: Numeric output

Solution

Costs | Other

Costs

Component	Net Present ($)	Initial Capital ($)	Total Annualized ($/yr)	Annualized Capital ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)
Centralized Generation:	101,981	16,225	7,978	3,636	1,560	2,782
Isolated Generation:	32,054	21,670	2,508	2,288	220	0
Distribution System:	48,856	40,138	3,910	3,140	770	
Totals:	182,891	78,033	14,396	9,064	2,550	2,782
Per Load:	1,759	750	138	87	25	27

Revenue

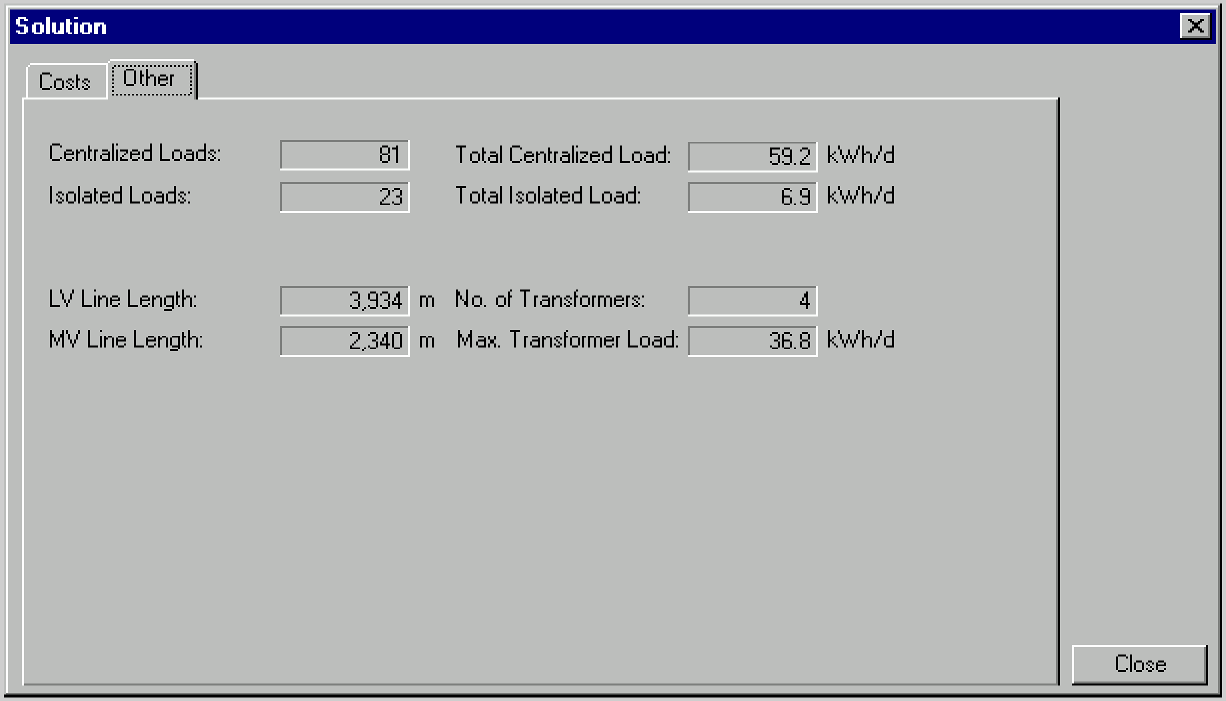
	Net Present ($)	Annual ($/yr)
Centralized Loads:	71,672	7,896
Isolated Loads:	9,585	1,056
Total:	81,258	8,952

Profit

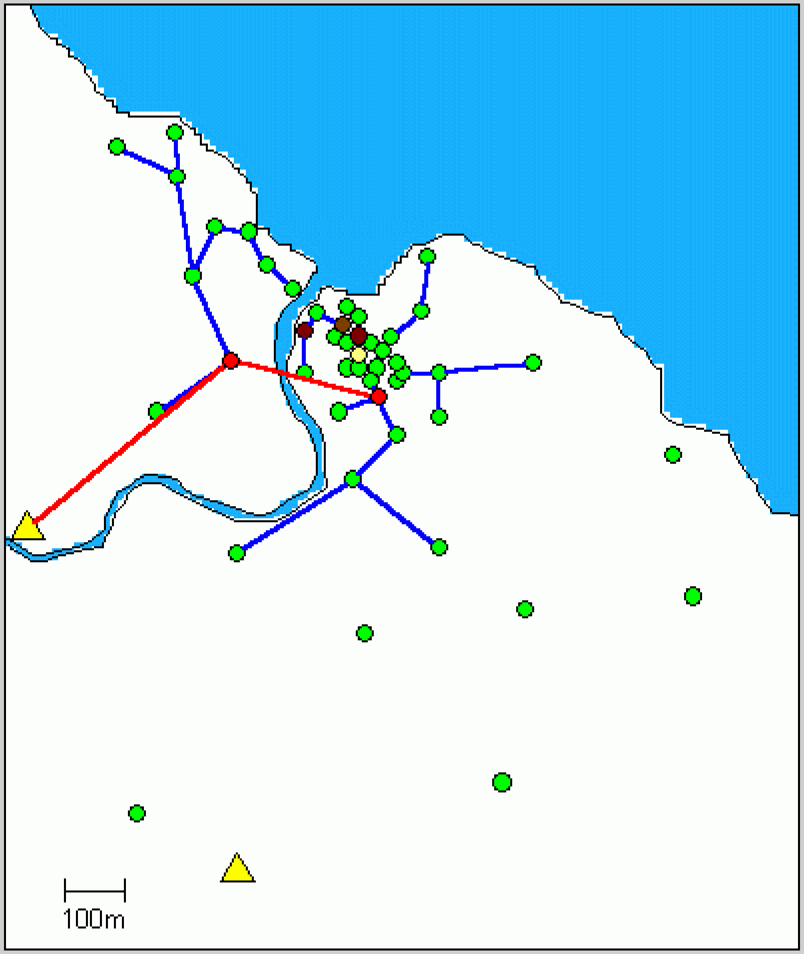
Net Present Profit:	-101,633	$
Annualized Profit:	-5,444	$/yr
Levelized COE:	0.594	$/kWh
Levelized Profit:	-0.224	$/kWh

Close

ViPOR: Numeric output

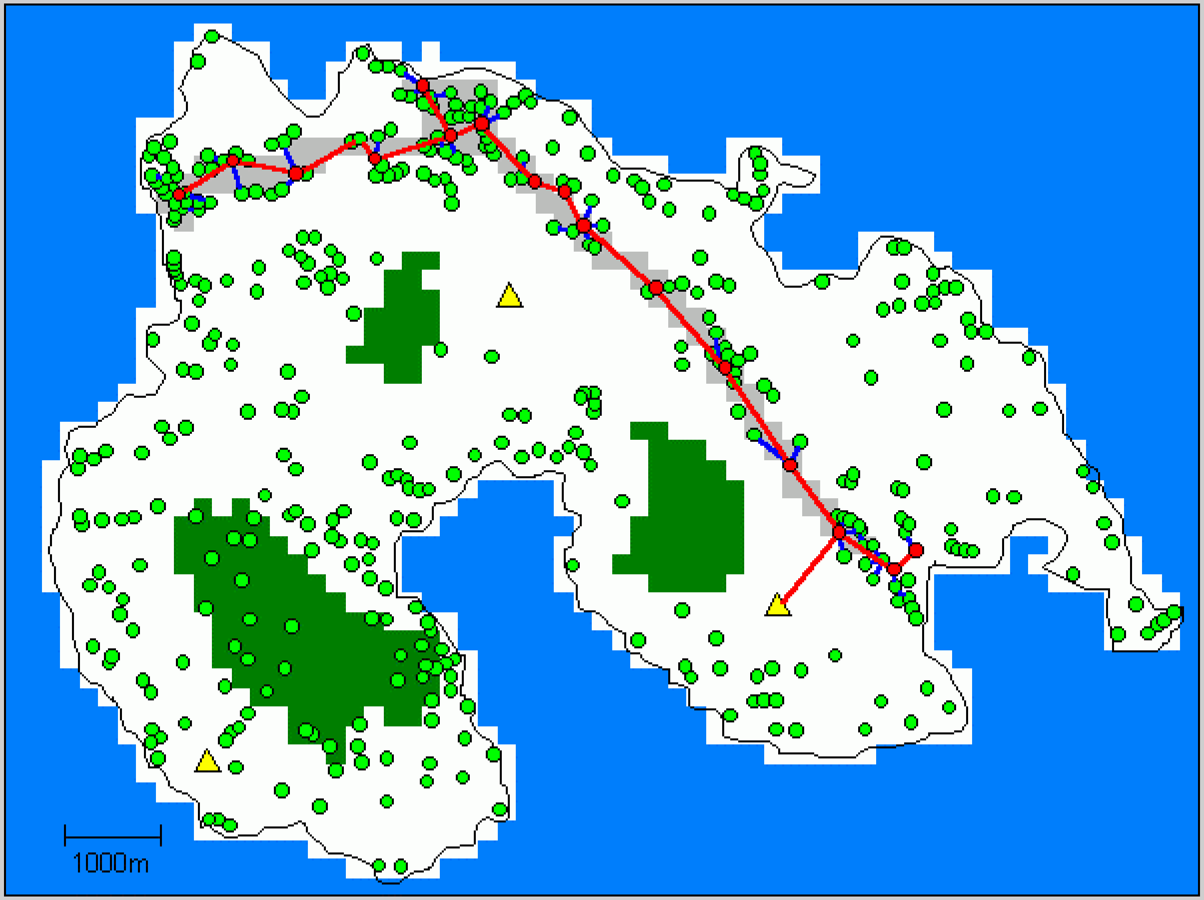


ViPOR: More examples



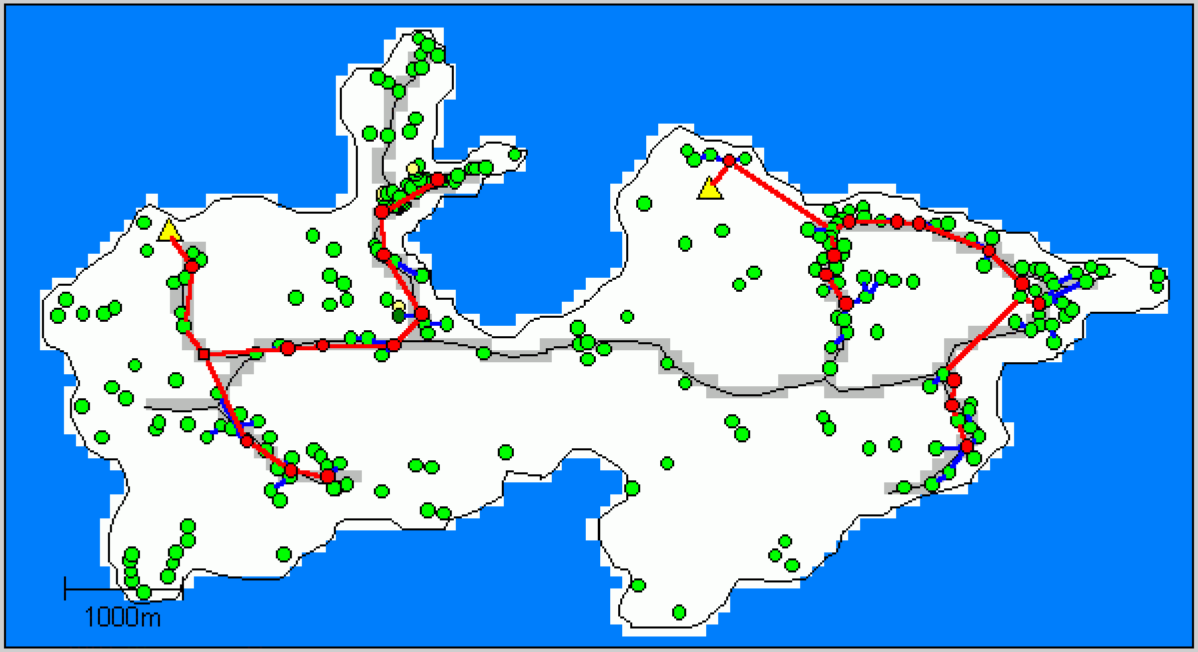
In this example, ViPOR has minimized river crossings because the river has been defined as high-cost terrain.

ViPOR: More examples



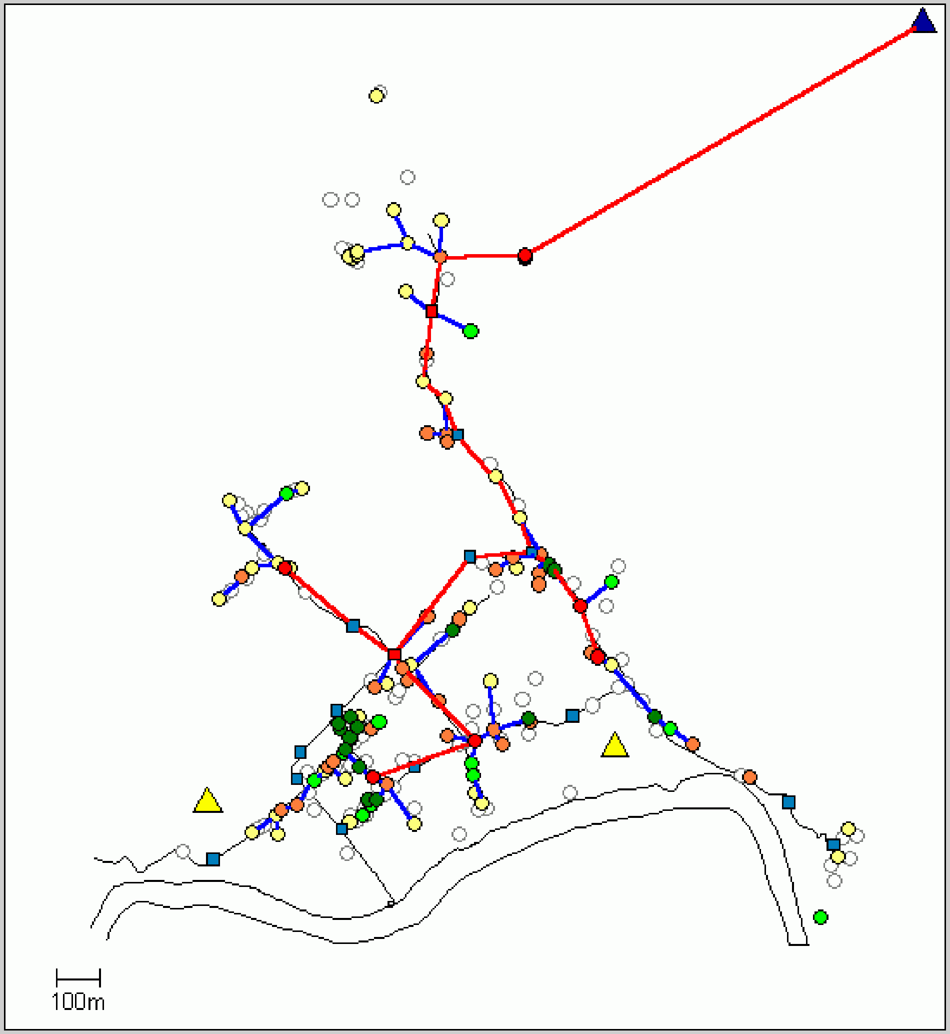
In this example, the grid follows the roadway closely.

ViPOR: More examples



In this example, ViPOR has chosen to build two separate distribution grids, each powered by a wind/diesel system.

ViPOR: More examples



In this example, ViPOR chose grid extension over a hybrid power system. A few houses were found to be best served by PV home systems.

Terrain information is omitted for clarity.

ViPOR: Future enhancements

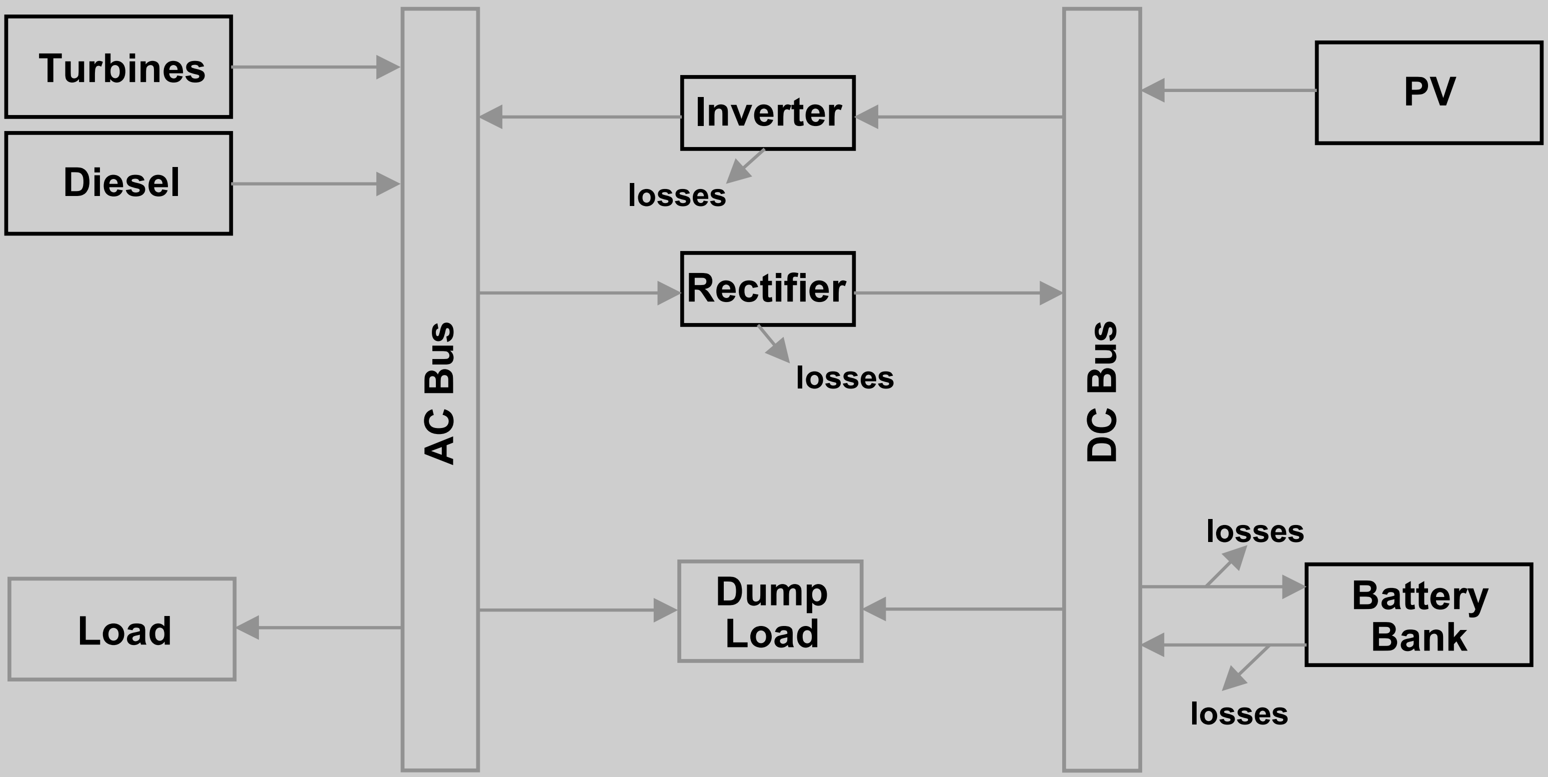
- Explicit calculation of voltage drops
- Calculation of power losses in distribution system
- Multiple transformer sizes
- Multiple wire sizes
- Tighter integration with HOMER

Hybrid Optimization Model for Electric Renewables

HOMER is an design model that determines the optimal architecture and control strategy of the hybrid system. It can also determine the sensitivity of the outputs to changes in the inputs.

HOMER performs an hourly time series analysis on each of hundreds or thousands of different system configurations.

HOMER: Simulation model

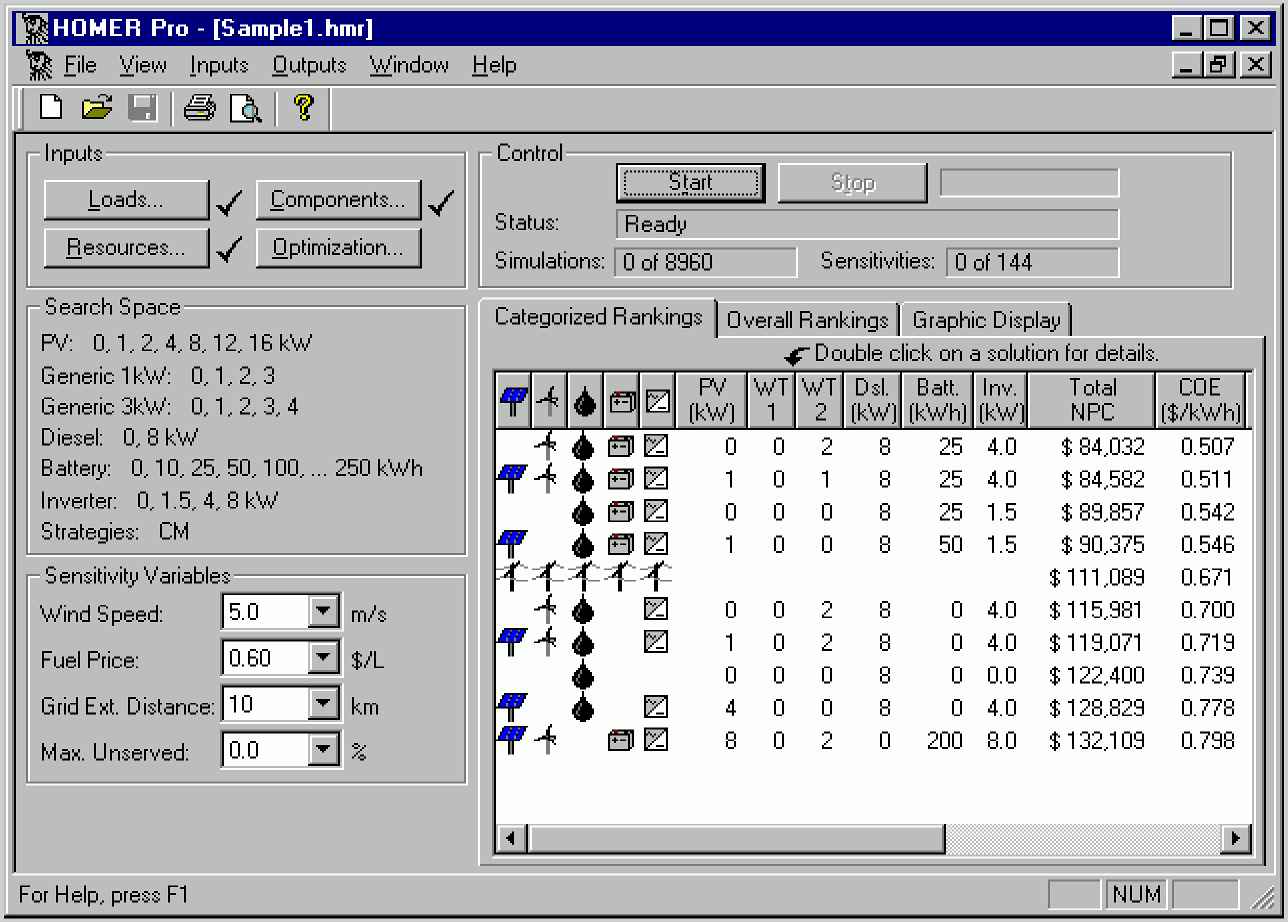


HOMER: Inputs

- Load data (primary and deferrable)
- Solar and wind speed data (hourly or monthly)
- Basic cost and performance data for each component
- Fuel price and interest rate
- Search space and constraints

	PV Array (kW)	Generic 1kW	Generic 3kW	Diesel (kW)	Battery (kWh)	Inverter (kW)
1	0.000	0	0	0.0	0.00	0.00
2	1.000	1	1	8.0	10.00	1.50
3	2.000	2	2		25.00	4.00
4	4.000	3	3		50.00	8.00
5	8.000		4		100.00	
6	12.000				150.00	
7	16.000				200.00	
8					250.00	
9						
10						

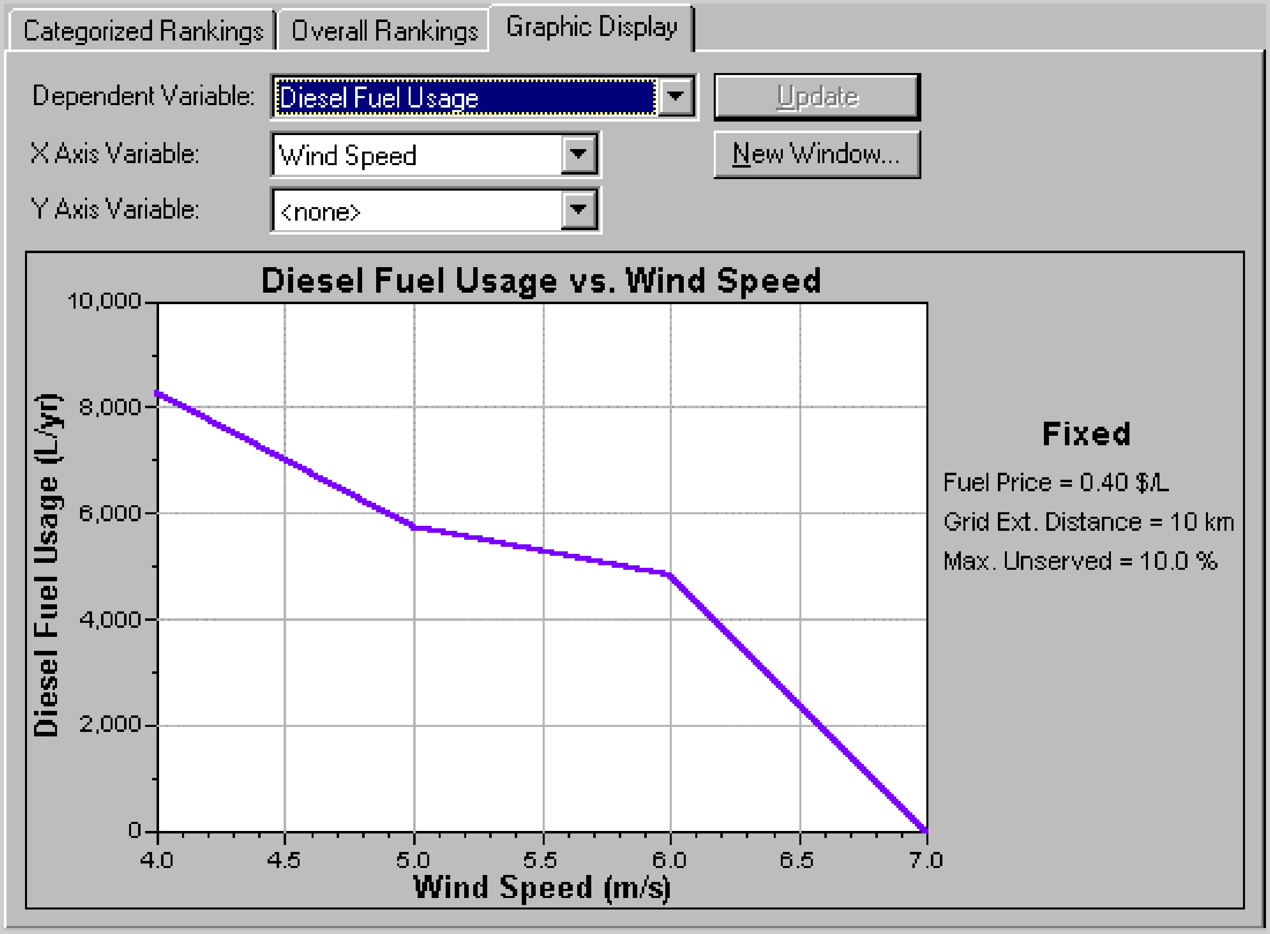
HOMER: Outputs



Solutions are rank-ordered by net present cost and displayed in the list control.

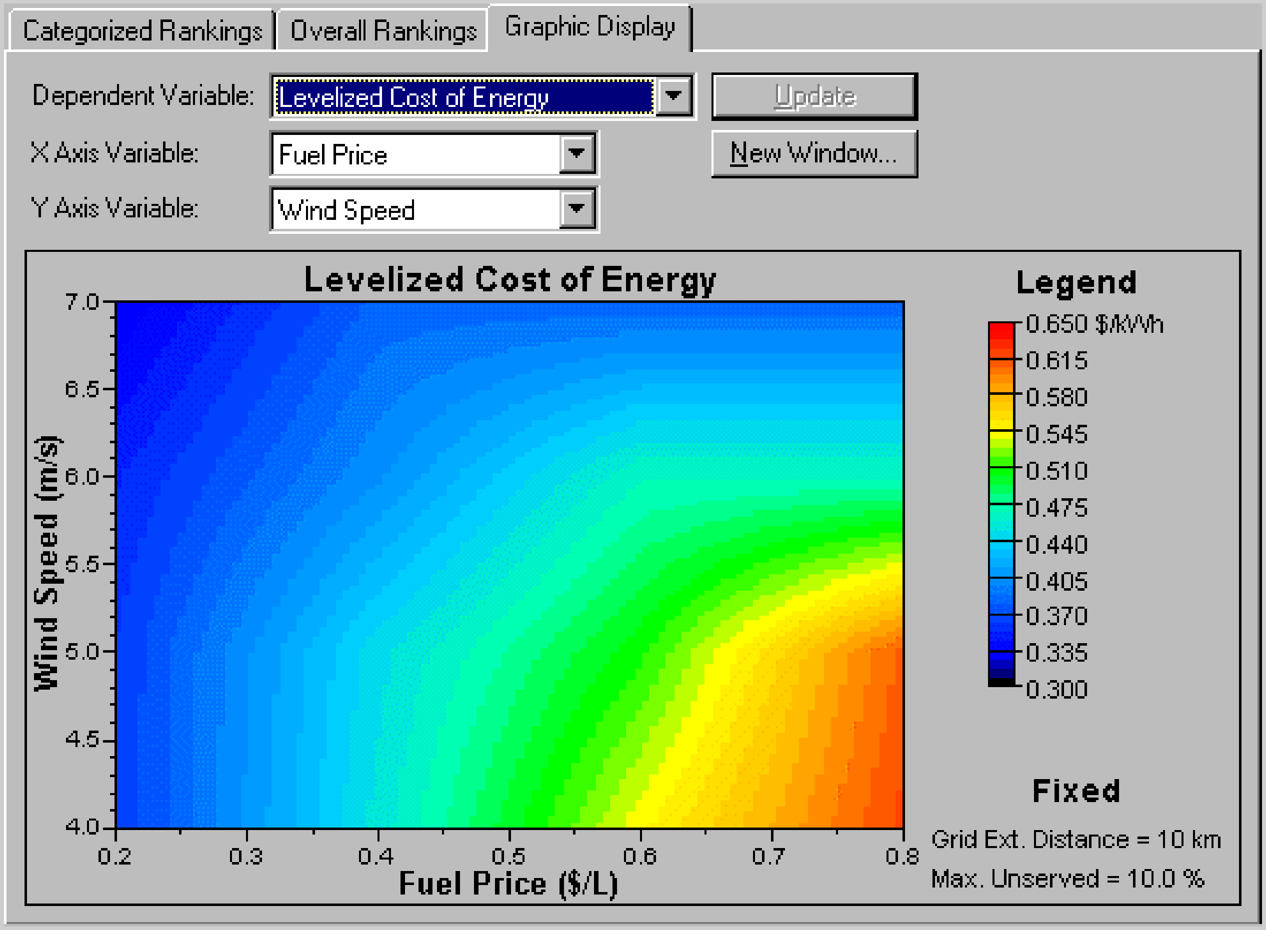
Detailed outputs can be viewed by double clicking on any solution in the list control.

HOMER: Outputs



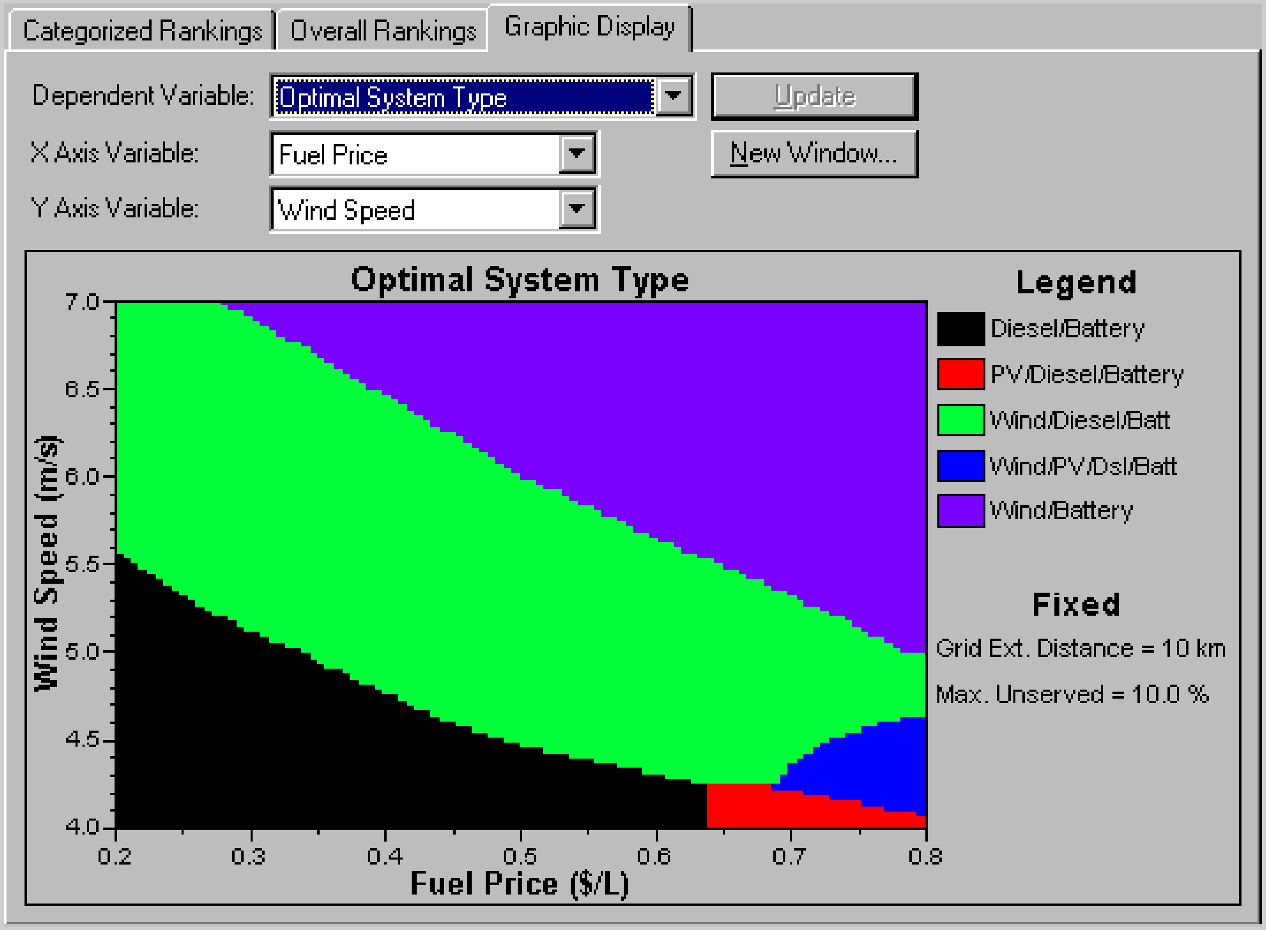
Sensitivity results are often best analyzed graphically.

HOMER: Outputs



Sensitivity results can be plotted versus one or two variables.

HOMER: Outputs



OST graph shows how optimal architecture changes under differing conditions.

HOMER: Detailed outputs

Simulation Results

Costs | Energy | Diesel | Hourly Data

Component	Initial Capital ($)	Total Annualized ($/yr)	Annualized Capital ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)
PV Array:	7,000	815	805	10	
Generic 3kW:	10,000	1,451	1,281	170	
Diesel:	7,000	4,070	1,452	610	2,008
Battery:	2,500	1,480	1,355	125	
Inverter:	2,917	503	469	33	
Totals:	29,417	8,318	5,362	948	2,008

Total Net Present Cost: $ 75,502 Levelized COE: 0.456 $/kWh

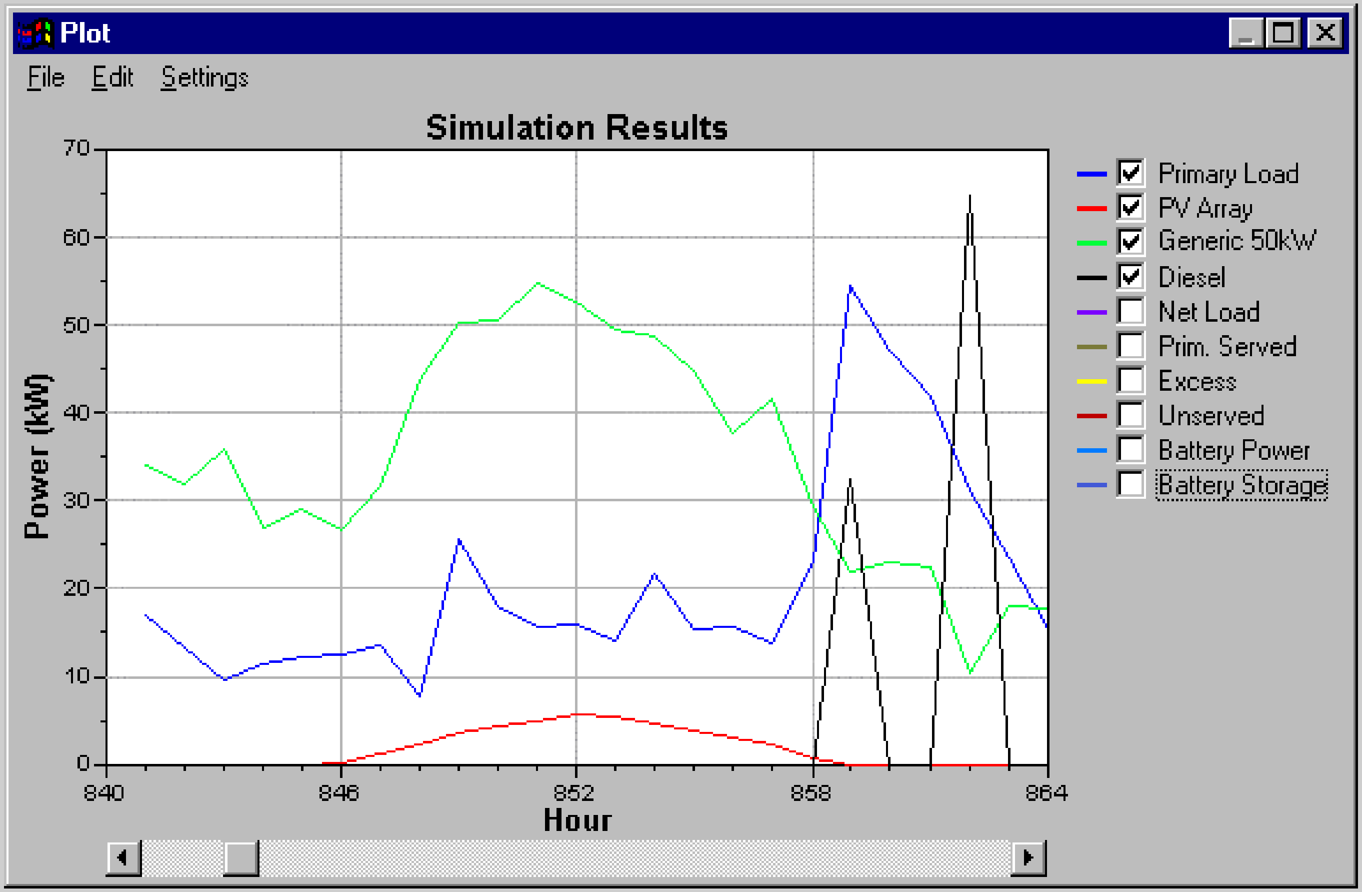
System Architecture:
- 1 kW PV
- 1 Generic 3kW
- 8 kW Diesel
- 25 kWh Battery
- 4 kW Inverter
- 3 kW Rectifier
- Combined
- Frugal Dispatch

Help

Close

Double clicking on any solution brings up the detailed outputs window.

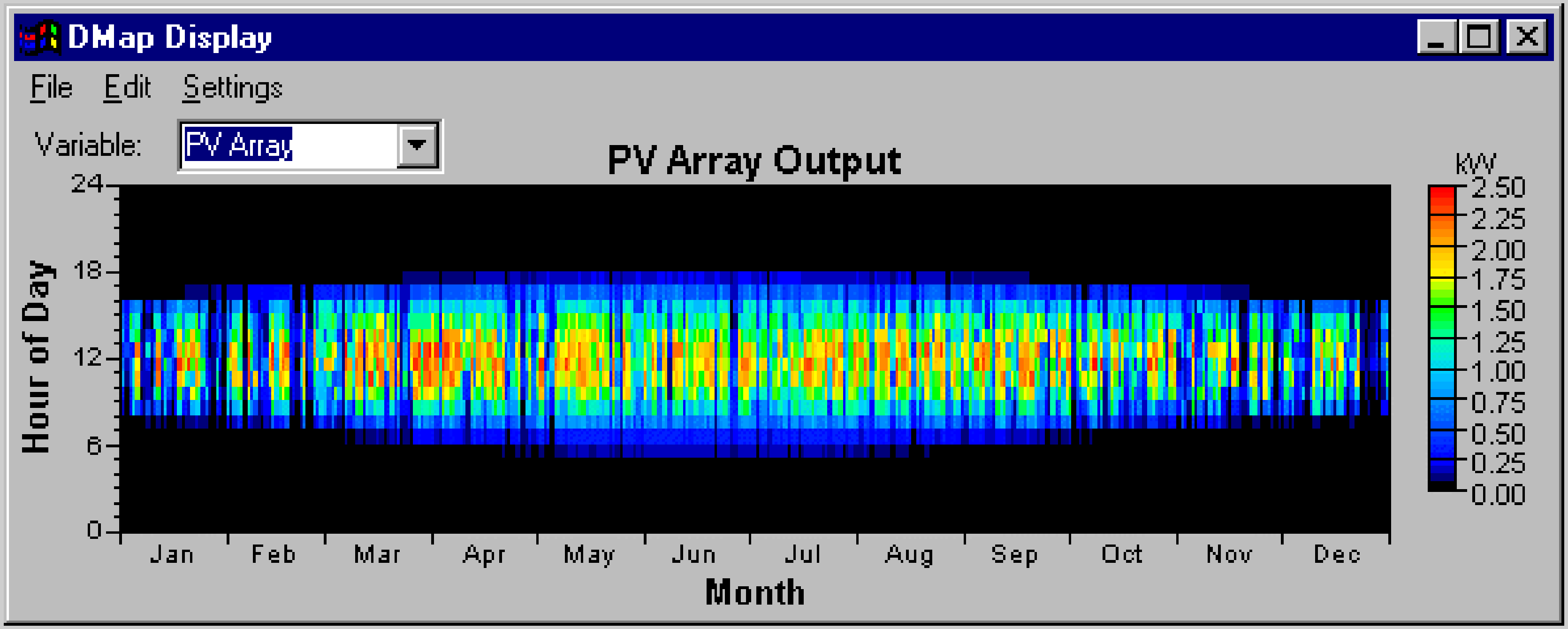
HOMER: Detailed outputs



Hourly data can be viewed as a time series plot...

HOMER: Detailed outputs

… or in DMap format.

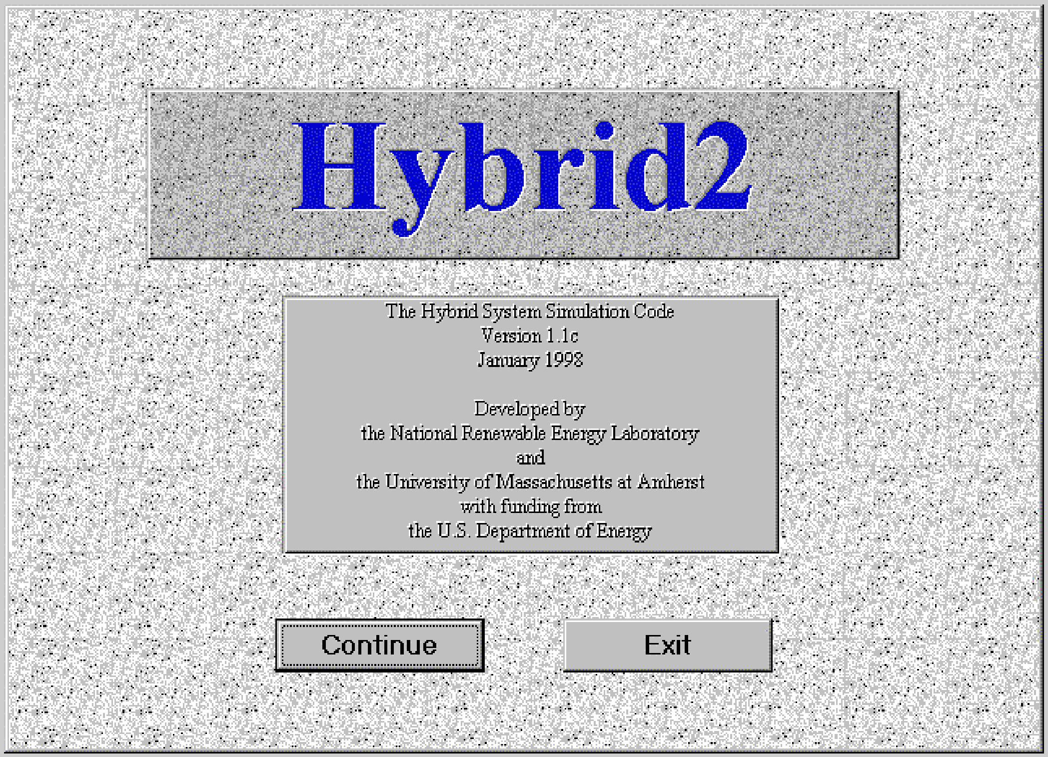


HOMER: Limitations and enhancements

- Limitations
  - Systems containing renewables must also contain battery storage
  - Assumes inverter can be used in parallel with diesel
  - Single diesel generator
  - Simple control strategies
  - Can model AC or DC loads, but not both
- Future enhancements
  - Microhydro, biomass
  - Multiple diesels
  - Diesel deadband

The Hybrid2 simulation software

A tool designed to accurately predict the long term performance of a wide variety of power systems made up of conventional fuel generators, wind generators, photovoltaics and energy storage through batteries



Hybrid2, the need for it:

- Detailed long-term predictions of potential hybrid power systems.
- Many organizations interested in the installation and use of hybrid power systems need modeling tool.
- Detailed analysis of options based on the output of screening models like HOMER.
- Validation of models created by vendors and independent evaluation of vendor predictions.
- Parametric analysis of system components and resource, providing the freedom to conduct imperical studies.

Utility of Hybrid2

- Assisting system designers by prediction of the *relative performance* of various system options:
  - energy sources
  - component sizes
  - system configurations
  - system dispatch/control
- Providing the *best available predictions* of the long-term performance for proposed system designs.
  - Hybrid2 will be able to predict future system performance only to the extent that the selected inputs actually reflect future conditions

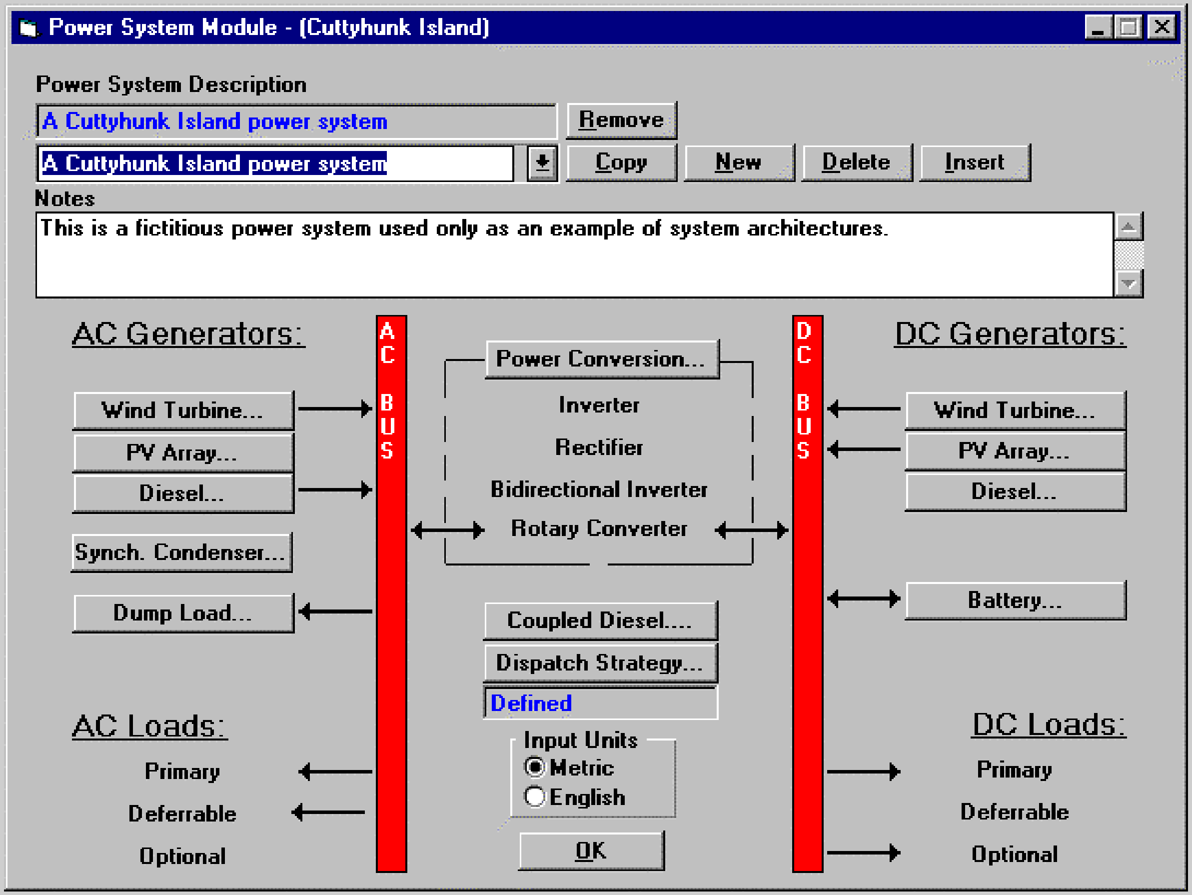
Hybrid2 Data Requirements

- Loads
  - Primary time series or daily load profile, Deferrable, and Optional loads
- Site/Resource parameters
  - Wind speed and incident solar time series
  - Ambient temperature time series or nominal value
  - Elevation, site position and wind turbulence parameters
- Power System
  - Configuration and components
  - Component performance parameters (Library)
  - Dispatch Strategy (Library)

Hybrid2 Software Features

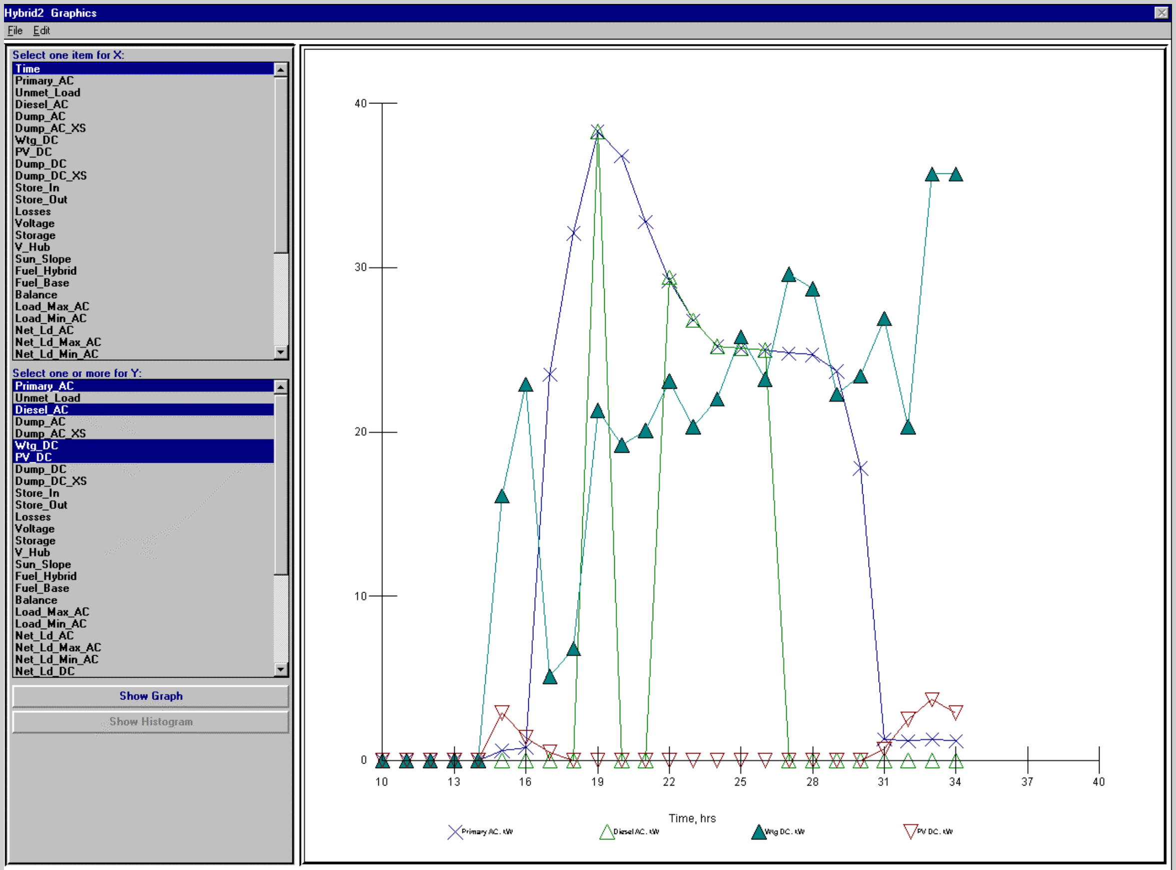
- Probabilistic/time series model: Accounts for the fluctuations of the wind and load during each time step
- Very diverse system architecture
  - AC, DC and combined systems can be modeled
  - System can include multiple wind turbines, multiple diesels, batteries, PV and 4 different types of power converters
- Detailed economic analysis
- On line library of manufactures equipment
- Detailed dispatching options: 17 different control parameters
- Hybrid systems glossary of commonly used terms
- Energy audit/estimation tool
- Resource data gap filler

Hybrid2 Power System Design



The power system is designed to meet the required loads using the resources available. This requires a fair amount of hybrid system and design experience.

Hybrid2 Results Interface



Simulation results displayed in a graphical format as well as a summary file which includes power flows from each component, loads, and system losses.

HOMER and Hybrid2

- Design philosophy: Simplicity vs. flexibility
- Use: Optimization vs. performance predictions
- System configuration: HOMER output is the input to Hybrid2
- Main differences

Hybrid2	HOMER
- Inter hour variability	- Resource data estimation
- Multiple diesels	- Dispatch optimization
- Dispatch flexibility	- Easy initial use
- Detailed output	- Summaries of different systems
- Engineering tool	- Options analysis

Model Availability

Web site:

http://www.rsvp.nrel.gov/analytical/model.html

- **ViPOR:** Demo of pre-release version available from website.
- **HOMER:** Available free on website, Express version is unrestricted; Pro version requires 60 day extensions.
- **Hybrid2:** Generally available through NREL. Provided with software, manuals and user support.

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